d] Density of states $\rho_{c,v}(E)$ for 2D structure (Quantum well)

↳ Assume $L_x = L_y = 1mm$, $L_z = 10\,A^\circ$

$$k_x = \frac{m\pi}{L_x} \qquad m = 1, 2, 3, \cdots$$

$$k_y = \frac{p\pi}{L_y} \qquad p = 1, 2, 3, \cdots$$

$$k_z = \frac{q\pi}{L_z} \qquad q = 1, 2, 3, \cdots$$

If $L_z = 10\,A^\circ$

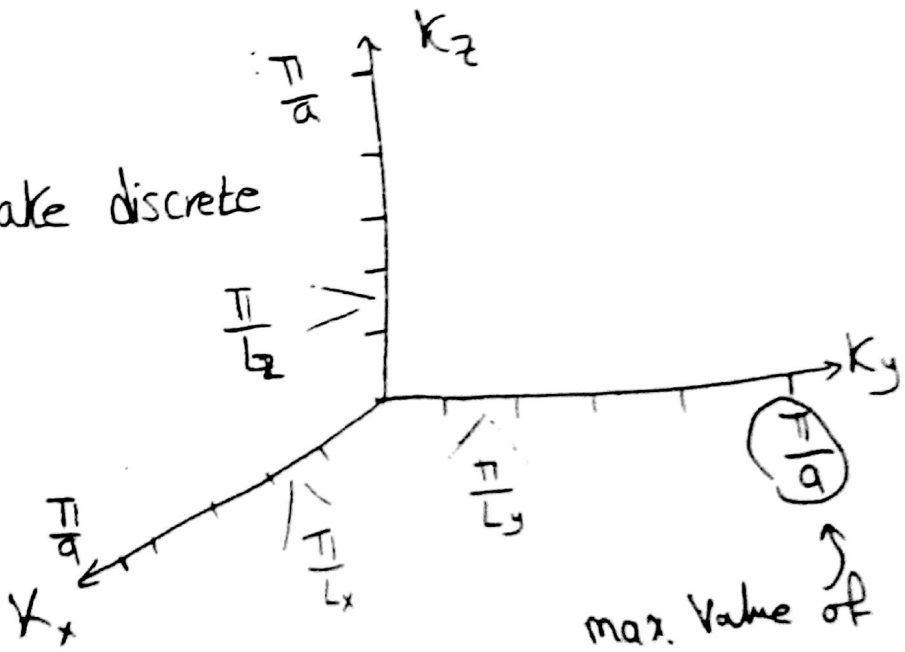
↳ Then k_z will take discrete values

for example:

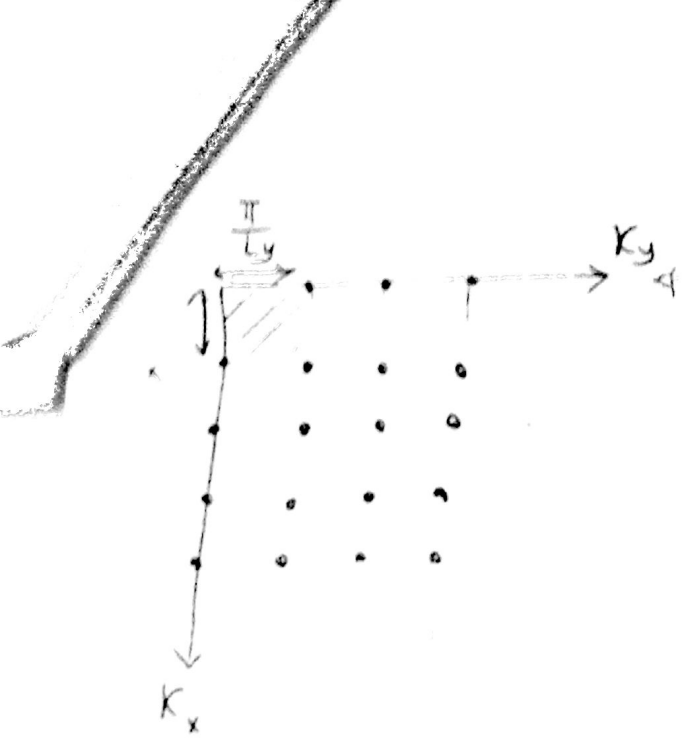
$$k_z\Big|_{q=1} = \frac{\pi}{L_z} = \frac{\pi}{10}$$

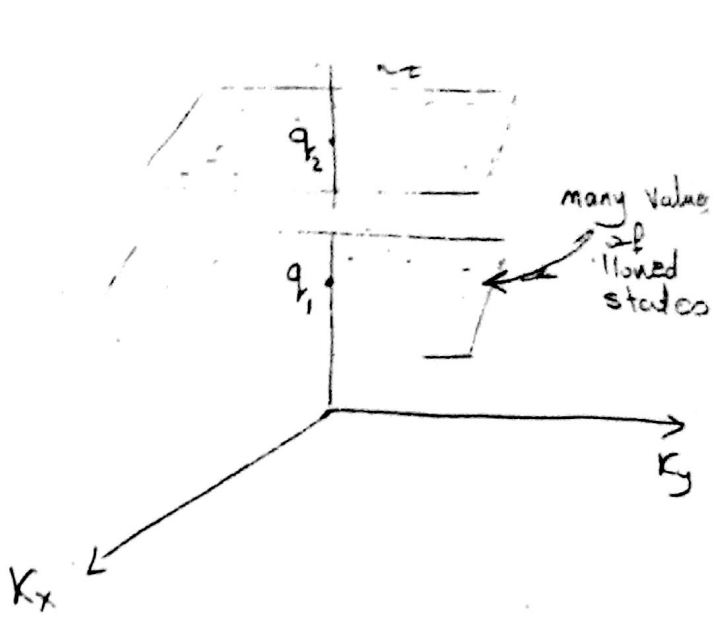
$$k_z\Big|_{q=2} = \frac{2\pi}{10} = \frac{\pi}{5}$$

$a = 5\,A^\circ$ in Semi Conductor



Scanned by CamScanner





→ Area of one state $= \left(\frac{\pi}{L_x}\right)\left(\frac{\pi}{L_y}\right)$

→ Area of all allowed states (up to E_n) $= (\pi K^2) \cdot \frac{1}{4}$

↑ بأخذ الاتجاه الموجب فقط من المحاور (+K)

لكل قيمة K هناك قيمة لـ E

Vector in 2D يرسم دائره يمثل عدد دائره نصف قطرها (K)

لان اتجاه (-K) هو اتجاه رجوع Spin of electron

→ No. of Allowed states $= \frac{\pi K^2}{4(\pi^2)} \cdot (L_x L_y) \times 2 = \frac{K^2 L_x L_y}{4\pi}$

$$N|_{\text{per unit volume}} = \frac{K^2 L_x L_y}{4\pi (L_x L_y L_z)} = \frac{K^2}{2\pi L_z}$$

$$P(E) = \frac{dN}{dE} = \frac{dN}{dK} \cdot \frac{d}{dE/dK}$$

$$\therefore N = \frac{K^2}{4\pi L_z} \Rightarrow \frac{dN}{dK} = \frac{2K}{2\pi L_z} = \frac{K}{\pi L_z}$$

Scanned by CamScanner

$$E = E_c + \frac{\hbar^2 k^2}{2m_c} \qquad |k^2| = k_x^2 + k_y^2 + k_z^2$$

$$\frac{dE}{dk} = \frac{2k\hbar^2}{2m_c} = \frac{k\hbar^2}{m_c}$$

$$\hookrightarrow \rho(E) = \frac{k}{\pi L_z} \cdot \frac{m_c}{k\hbar^2} = \frac{m_c}{\hbar^2 \pi L_z}$$

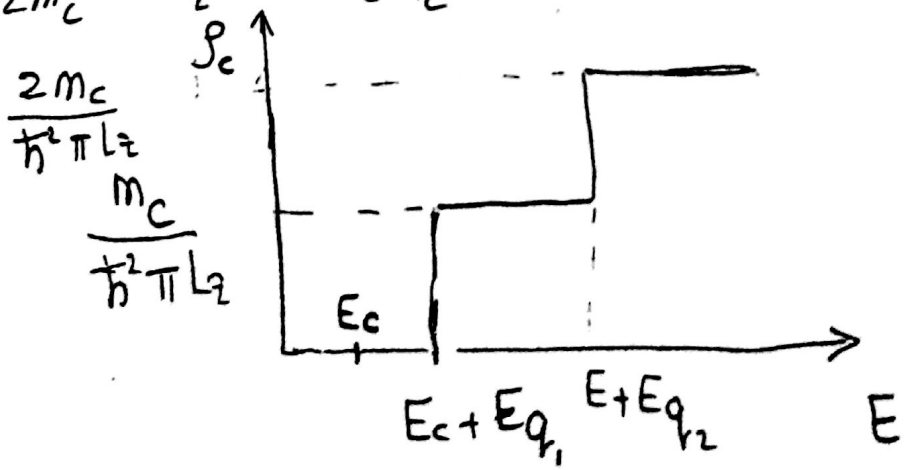
Constant does not depend on k

$$E = E_c + \frac{\hbar^2 (k_x^2 + k_y^2 + k_z^2)}{2m_c}$$

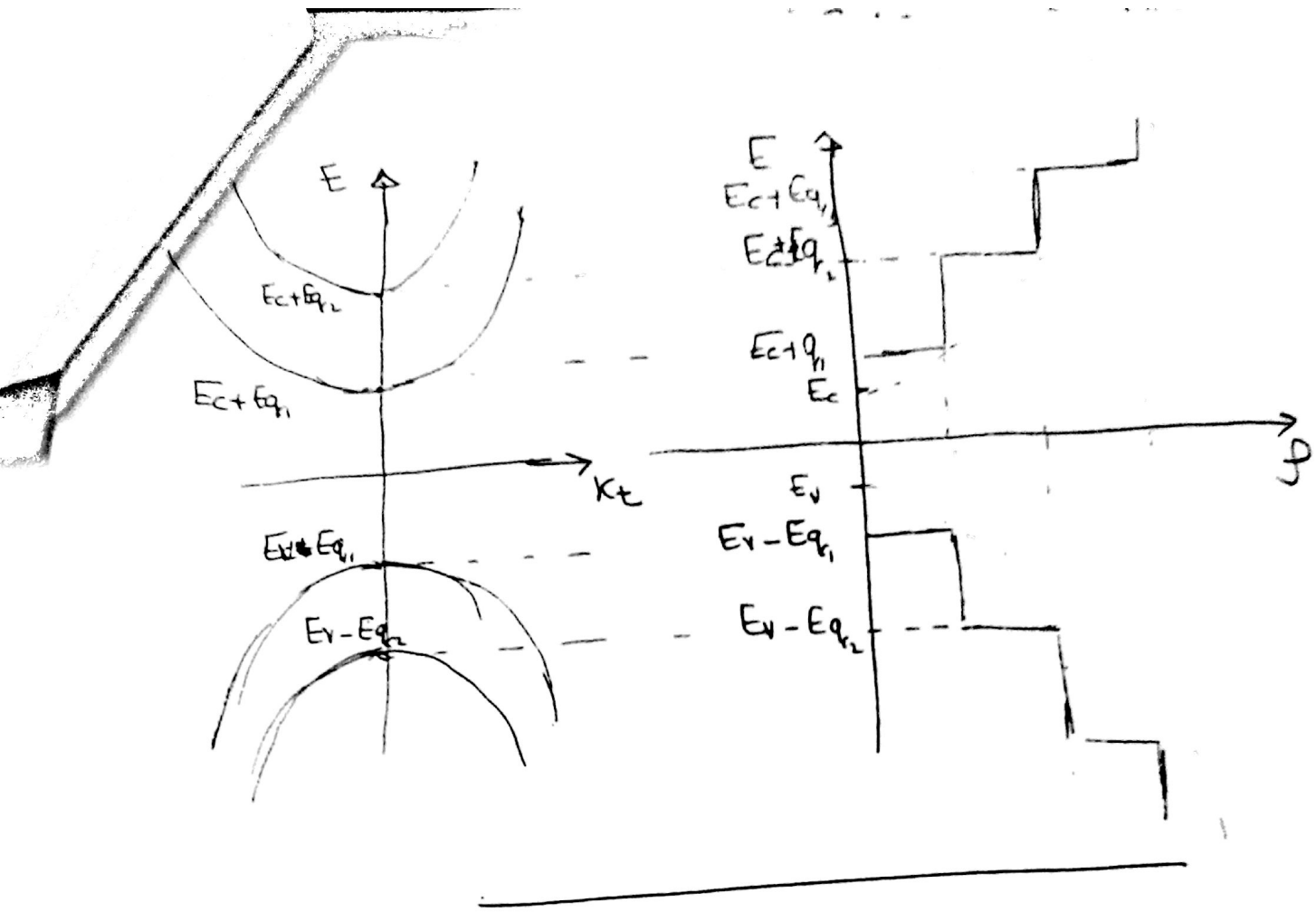
$$= E_c + \frac{\hbar^2 k_z^2}{2m_c} + \frac{\hbar^2 (k_x^2 + k_y^2)}{2m_c}$$

$$= E_c + \frac{\hbar^2}{2m_c}\left(\frac{q_1 \pi}{L_z}\right)^2 + \frac{\hbar^2 k_t^2}{2m_c}$$

$$E_1 = E_c + \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_z}\right)^2 + \frac{\hbar^2 k_t^2}{2m_c} = E_c + E_{q_1} + \frac{\hbar^2 k_t^2}{2m_c}$$



Scanned by CamScanner



Scanned by CamScanner

Q(4)

B Repeat the solution of (a) when dimensions of structure doubles?

~Sol

E-K Diagram and Density of states won't Change

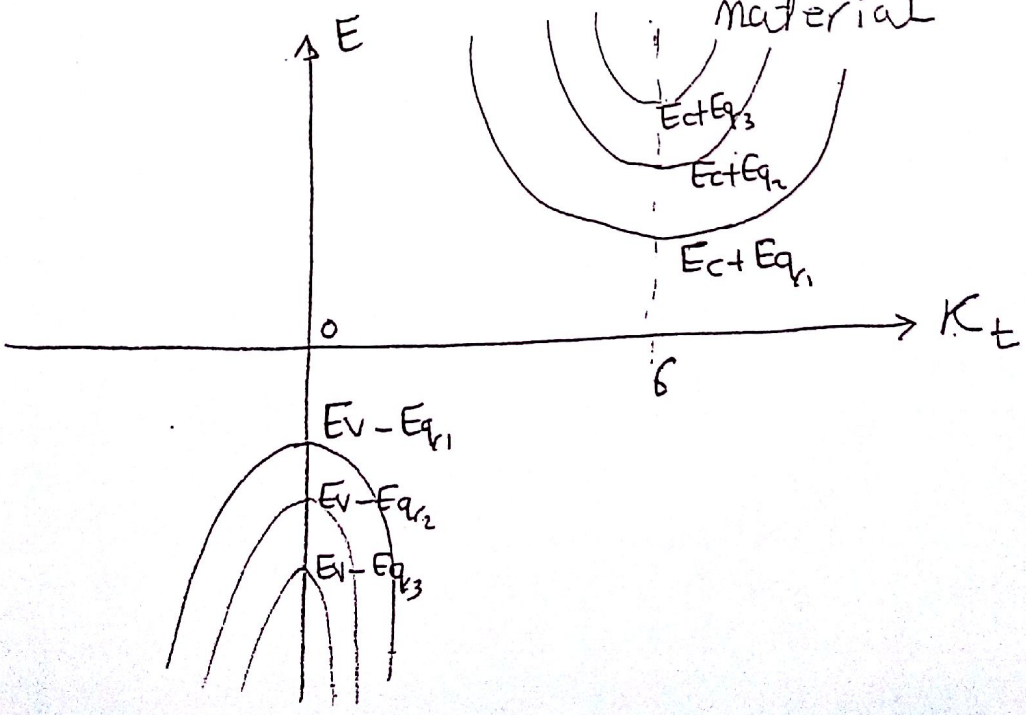
only the No. of states will be ~~doubled~~ increased

$N = N * \text{Volume}$

$= 10^{19} * (0.2)^3 = 8 * 10^{16}$ states

Q(4) C Repeat the solution of @ when dimensions of structure changed to be

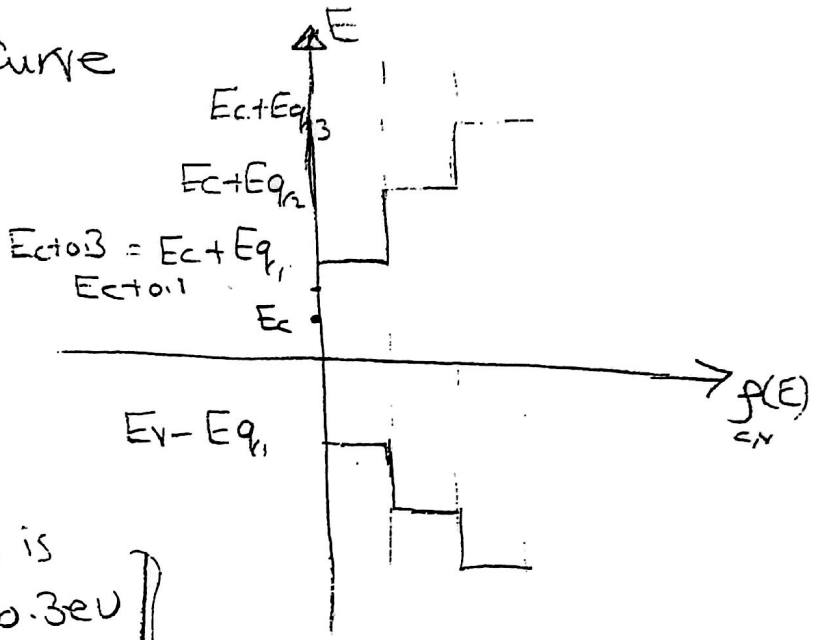
1mm * 1mm * 10 A° → Quantum well not Bulk material



Scanned by CamScanner

Density of State Curve

$$\rho(E) = \frac{m_c}{\hbar^2 \pi L_z}$$



↳ No. of States from $E_c \rightarrow E_c + 0.1eV$

∴ Small energy in C.B is $E_c + E_{q_1} = E_c + 0.3eV$

∴ $\rho(E)$ in this reigon = Zero

$$E_{q_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_z}\right)^2$$

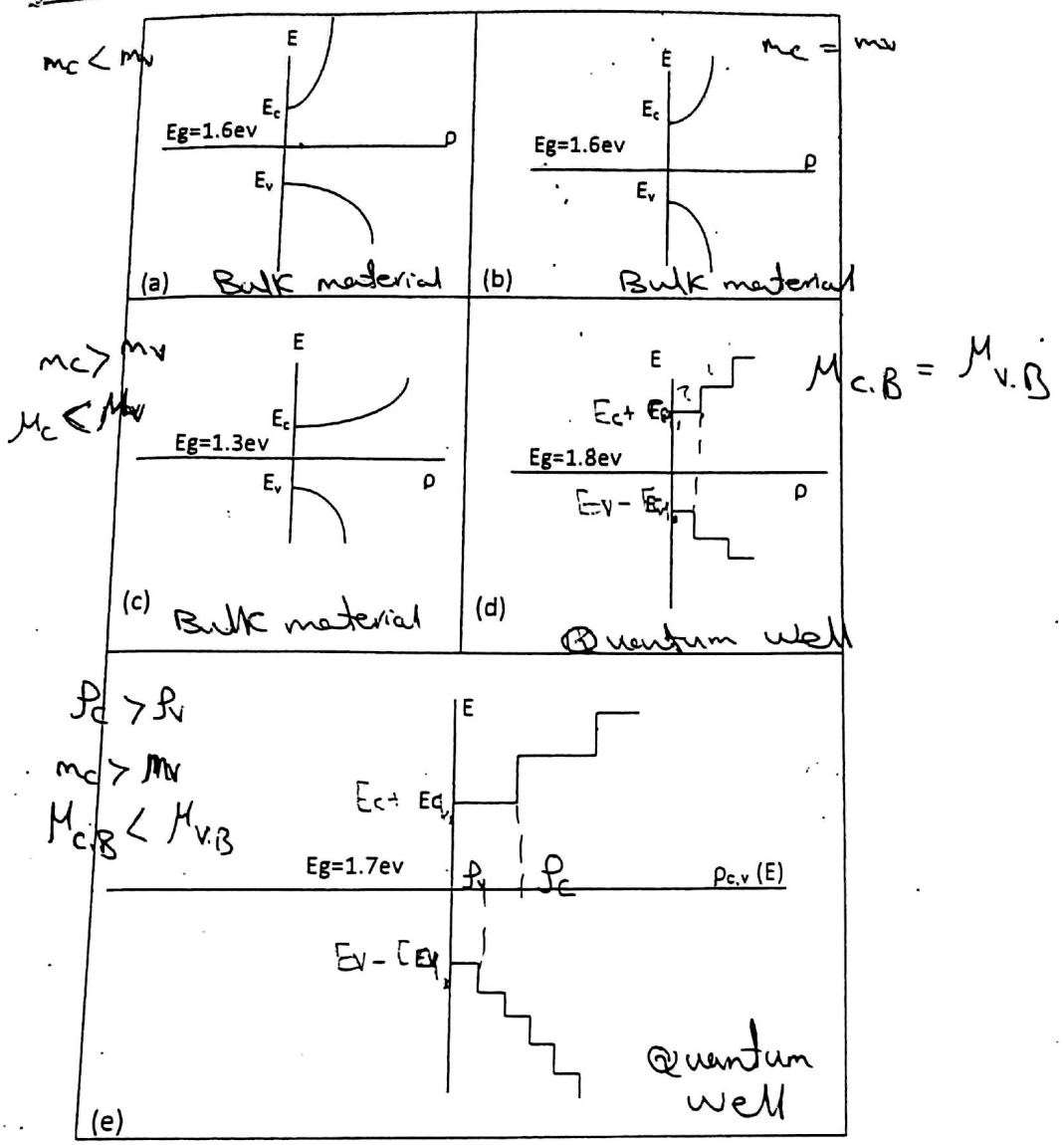
$$= \frac{(1.05*10^{-34})^2}{2*0.98*9.1*10^{-31}} * \left(\frac{\hbar}{10*10^{-9}}\right)^2$$

$$= 6.1*10^{-20}\ J$$

$$E_{q_1} = 0.38\ eV$$

Scanned by CamScanner

3- Given the following curves for $\rho_{c,v}(E)$



a) Determine the type of each structure based on its given density of states

b) Draw E-K diagram qualitatively for each material described by its density state.

c) Comment on the carriers ~~mobilities~~ Mobilities in each figure.

d) Estimate the values (E_{m1},E_{m2},E_{p1},E_{p2},E_{q1} and E_{q2})in curve (d) assuming structure dimensions are 1mm ×5mm ×8A and m_e=.067m_0, $m_0 = 9.1\times10^{-31}$ kg

e) Using the information given in (d) calculate the density of states per unit volume at

i)$E=E_c+E_{q1}/2$ ii) $E=E_c-E_{q1}/2$ iii) $E=E_c+1.5\,E_{q1}$ iv) $E=E_v+2E_{q1}$.

f) Using the information given in (d) calculate the number of allowed state within the whole structure for energy ranging from i) E_c to $E_c+E_{q1}/2$ ii) E_c+E_{q1} to E_c+2E_{q1}

g) Estimate the values of allowed states per unit volume for structure represented by curve (a) at energies (a)E_v-.1ev (b)E_c+0.1ev (c) E_c, assuming m_c=.08m_0 and m_v=0.28m_0

h) Estimate the total number of allowed states in the conduction band in structure represented by curve (a) assuming their dimensions are 1mm × 5mm × 3mm. Ec + 2ev

(9)

Scanned by CamScanner

4 Using the information given in ① Calculate the no. of allowed state within the whole structure for energy ranging from i) $E_c \to E_c + Eq_1/2$

ii) $E_c \to E_c + Eq_1$

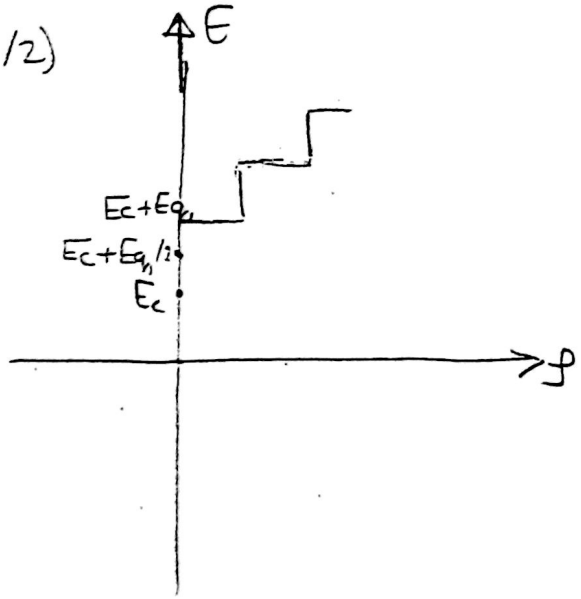
iii) $E_c \to E_c + 2Eq_1$

i) $N \to (E_c \to E_c + Eq_1/2)$

$N = \text{zero}$

ii) $E_c \to E_c + Eq_1$

$N = 0$



iii) $N = \int_{Ec}^{Ec+2Eq_1} p(E)\, dE$ (per unit volume)

$$= \int_{Ec+Eq_1}^{Ec+2Eq_1} p(E)\, dE = \frac{mc}{\pi \hbar^2 L_z}\left[Ec + 2Eq_1 - Ec - Eq_1\right]$$

$$= \frac{mc}{\pi \hbar^2 L_z} Eq_1$$

$$= \frac{0.067 * 9.1 * 10^{-31} \ (3.55 * 10^{-28})}{\pi (1.05 * 10^{-34})^2 (8 * 10^{-10})}$$

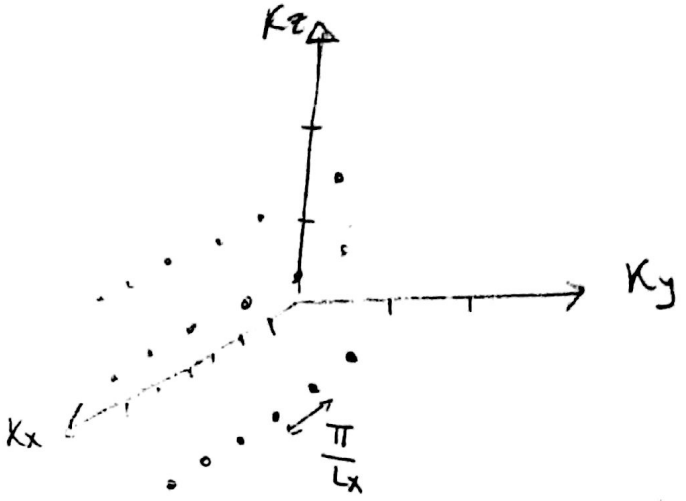
$$= 7.7 * 10^{17} \ m^{-3}$$

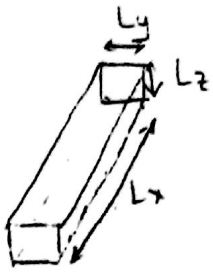
$$N = 7.7 * 10^{17} * (1 * 10^{-3} * 5 * 10^{-3} * 8 * 10^{-10})$$

$N = 3.1 * 10^3$ state

Scanned by CamScanner

Density of states $\rho_{c,v}(E)$ for 1D structure (Nano Wire)





↳ Length of one state $= \frac{\pi}{L_x}$

↳ In 2D → Area
↳ In 3D → Volume
↳ In 1D → length

↳ length of all allowed state $= K * \frac{1}{2}$

الجزء للموجب فقط

↳ $N = 2 * K * \frac{1}{2} = K$

Spin of electron

$\therefore N/\text{per unit Volume} = \frac{K}{\frac{\pi}{L_x}} = \frac{L_x K}{\pi (L_x L_y L_z)} = \frac{K}{\pi L_y L_z}$

↳ $\rho(E) = \frac{dN}{dK} \cdot \frac{1}{dE/dK} = \frac{1}{\pi L_y L_z} \cdot \frac{m_c}{\hbar^2 K}$

$E = E_c + \frac{\hbar^2 K^2}{2m_c}$

$\frac{dE}{dK} = \frac{\hbar^2 K}{m_c}$

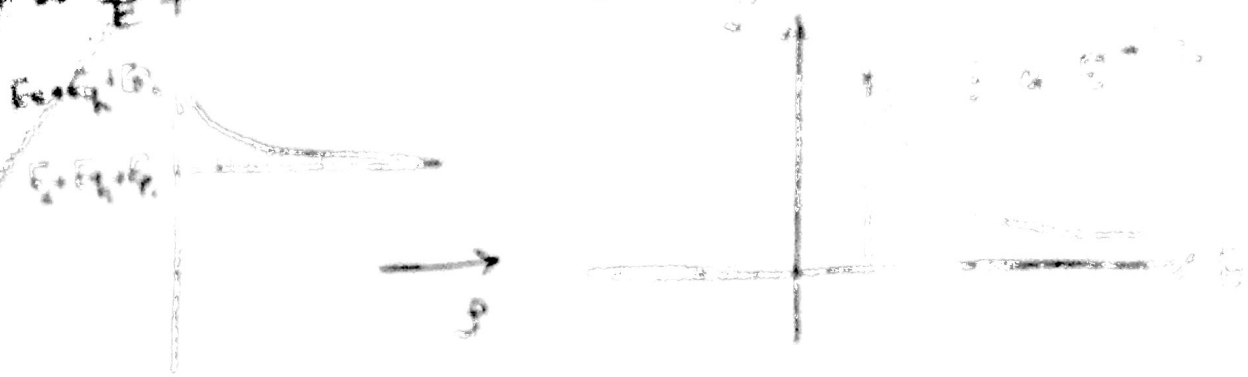
$\therefore \rho(E) = \frac{1}{\pi L_y L_z} \left(\frac{m_c}{\hbar^2}\right) (2)^{-\frac{1}{2}} \left(\frac{m_c}{\hbar^2}\right)^{-\frac{1}{2}} (E-E_c)^{-\frac{1}{2}}$

$= \frac{1}{\pi L_y L_z} \left(\frac{m_c}{\hbar^2}\right)^{\frac{1}{2}} (E-E_c)^{-\frac{1}{2}}$

$\therefore K = (E-E_c)^{\frac{1}{2}} \left(\frac{2m_c}{\hbar^2}\right)^{\frac{1}{2}}$

Scanned by CamScanner

$$\therefore \frac{P(E)}{E} = \sqrt{\frac{m^*}{2}} \cdot \frac{1}{\pi^2 L_y L_z} \cdot (E - E_c)^{-1/2}$$



(3)

d) Estimate the values (E_{m_1}, E_{m_2}, E_{p_1}, E_{p_2}, E_{q_1}, E_{q_2}) in curve (d) assuming structure dimensions are $1mm * 5mm * 8A^\circ$, $m_c = 0.067\ m_0$

$m_0 = 9.1 * 10^{-31}\ kg$

Sol

$$E_{m_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_x}\right)^2 = \frac{(1.05*10^{-34})^2\,\pi}{2*0.067*9.1*10^{-31}}\left(\frac{1}{L_x}\right)$$

$$= 2.84*10^{-37} * \frac{1}{1*10^{-3}} = 2.84*10^{-34}\ J$$

$$= 1.77*10^{-15}\ eV$$

$$E_{m_2} = \frac{\hbar^2}{2m_c}\left(\frac{2\pi}{L_x}\right)^2 =$$

$$E_{p_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_y}\right)^2 = \frac{2.84*10^{-37}}{5*10^{-3}} = 3.55*10^{-16}\ eV$$

$$E_{p_2} = \frac{\hbar^2}{2m_c}\left(\frac{2\pi}{L_y}\right)^2 = 7.1*10^{-16}\ eV$$

$$E_{q_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_z}\right)^2 = \frac{2.84*10^{-37}}{8*10^{-10}} = 3.55*10^{-28}\ J$$

$$= 2.21*10^{-9}\ eV$$

$$E_{q_2} = \frac{\hbar^2}{2m_c}\left(\frac{2\pi}{L_z}\right)^2 = 4.43*10^{-9}\ eV$$

Scanned by CamScanner

(3)[d] Estimate the Values ($E_{m_1}, E_{m_2}, E_{p_1}, E_{p_2}, E_{q_1}, E_{q_2}$) in Curve (d) assuming Dimensions are

$1mm * 5mm * 8A^\circ$, $m_c = 0.067\, m_o$

$m_o = 9.1 * 10^{-31}\ Kg$

Sol:

1) $E_{m_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_x}\right)^2 = \frac{(1.05*10^{-34})^2}{2*0.067*9.1*10^{-31}} * \left(\frac{\pi}{1*10^{-3}}\right)^2$ = ✓ J

2) $E_{m_2} = \frac{\hbar^2}{2m_c}\left(\frac{2\pi}{L_x}\right)^2 =$ 4 * نفس القيمة =

3) $E_{p_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_y}\right)^2 =$ ✓✓

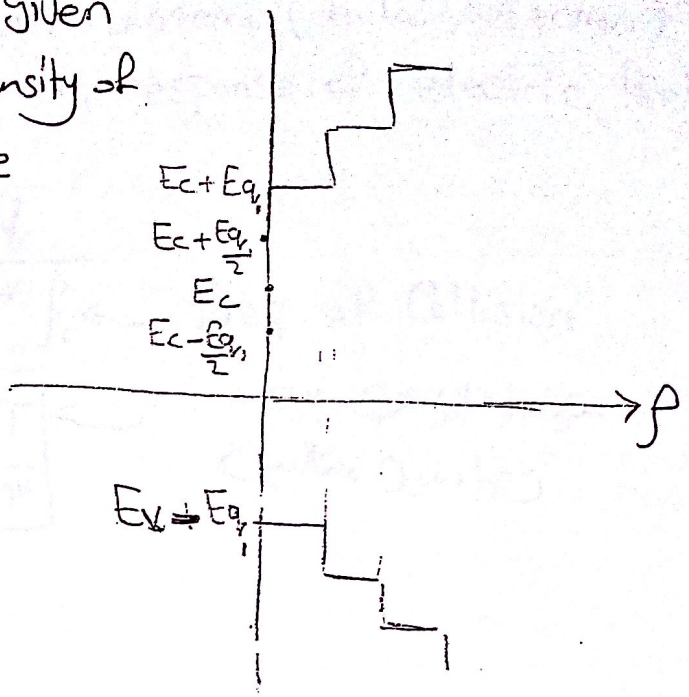
4) $E_{p_2} = \frac{\hbar^2}{2m_c}\left(\frac{2\pi}{L_y}\right)^2 = 4*$ = ✓

5) $E_{q_1} = \frac{\hbar^2}{2m_c}\left(\frac{\pi}{L_z}\right)^2$

6) $E_{q_2} = \frac{\hbar^2}{2m_c}\left(\frac{2\pi}{L_z}\right)^2 = 4 * \left(\frac{\hbar^2 * \pi}{L_z}\right)^2 \cdot \frac{1}{2m_c}$

Scanned by CamScanner

e) Using the information given in d Calculate the density of states per unit Volume at



i) $E = E_c + Eq_1/2$

↳ $\rho(E) = 0$

ii) $E = E_c - Eq_1/2$

↳ $\rho(E) = 0$

iii) $E = E_c + 1.5\,Eq_1$

↳ $\rho_c(E) = \frac{m_c}{\pi \hbar^2 L_z} = \frac{0.067 * 9.1 * 10^{-31}}{\pi^* (8*10^{-10})(1.05*10^{-34})^2}$

$= 2.2 * 10^{45}\ m^{-3}$

$= 2.2 * 10^{39}\ cm^{-3}$

iv) $E = E_c + 2Eq_1$

$\rho_c(E) = \frac{m_c}{\pi \hbar^2 L_z} = 2.2 * 10^{39}\ cm^{-3}$

Scanned by CamScanner

Mobility Ability of Carriers (holes / electrons) to move in response of electric field.

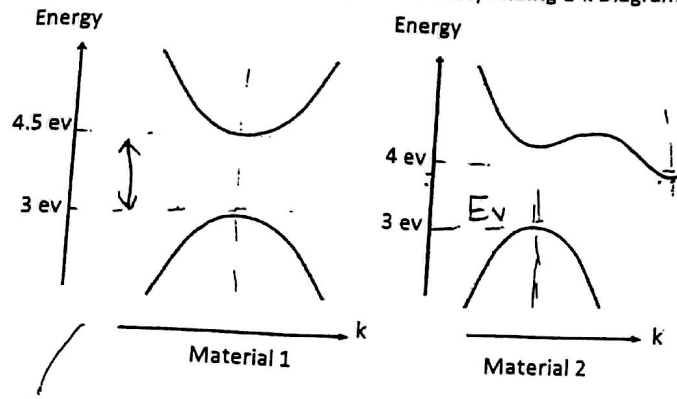
$$\mu = \frac{q}{m^* f_c}$$ ← f_c freq. of Collision

$$\boxed{\mu = \frac{q\tau}{m^*}}$$ ← τ متوسط الزمن بين تصادمين متتاليين

$$\mu \propto \frac{1}{m^*}$$

Scanned by CamScanner

Q10. Determine the characteristics (mobility, effective mass, direct or indirect and the energy bandgap) of two semiconductor materials using their corresponding E-k Diagrams shown below.



Eg = 1 ev

↳ peaks occur at different (k)

Direct Band Gap

Eg = 1.5 ev

Indirect Band gap

↳ Effective mass

$m_c = m_v$

↳ as Curvature of C.B ≃ Curvature of V.B

↳ Curvature of C.B > V.B

$m_c < m_v$

↳ Mobility

$\mu_{C.B} = \mu_{V.B}$

↳ $\mu_c > \mu_v$

summary of Lec (1)

Q1. Complete the following sentences

1. The characteristics of the deflector can be altered by applying Sound
2. The characteristics of the devices can be altered by applying magnetic fields
3. The characteristics of the Electro optic can be altered by applying electric fields.
4. Optical electronics are defined as devices interact with light
5. Optical circuit board communications are necessary for optical Isolation
6. Optical electronic chips are composed of Photo detector and Laser diode
7. Optoelectronic devices are based on the Semiconductor materials that have electrical conductivities within the range 10^{-6} to 10^{3}
8. The electrical conductivities of the semiconductor materials can be altered by Temperature Doping and Illumination

Magento optic

Hint: see *lecture 1*

(13)

Scanned by CamScanner

5] Define the wavelength (μm) of the (emitted/absorbed) photon of (from/by) the Semi Conductor Materials Silicon, Germanium and GaAs

Material	E_g	$\lambda < \frac{h.c}{E_g}$
Si	1.1	$\lambda = 6.625 * 10^{-34} \cdot \frac{3 * 10^8}{1.1 * 1.6 * 10^{-19}} = 1.12$ μm
Ge	0.67	1.85 μm
GaAs	1.42	0.874 μm

$E_{ph} > E_g$

$h.\frac{c}{\lambda} > E_g$

$$\boxed{\lambda < h.\frac{c}{E_g}}$$

Scanned by CamScanner

Semiconductor Materials

Semiconductor	Bandgap energy E_g (e.V)
1] Silicon Si	1.1 eV
2] Germanium Ge	0.67 eV
3] Gallium Arsenide GaAs	1.42 e.V

Plank_Einstien Relation

∴ Energy of photon = $E = h \cdot f \leftarrow$ freq. $= h \cdot \frac{c}{\lambda}$

(h: planck constant)

$$\therefore \lambda = h \cdot \frac{c}{E}$$

↳ To transfer electron from Valence band to Conduction band → we need photon with Absorbed

$$E_{ph} > E_g$$

↳ When electron loss its energy and return to Valence band → it emit photon

$$E_{ph} > E_g$$

Note

→ SemiConductor at $T = 0°K$ → like insulator
لا يوجد الكترونات في الـ Conduction Band وكل الالكترونات في الـ Valence

② at $T = 300°K \rightarrow E = K \cdot T = 0.025$ eV

↳ Consentration of Carrier in Si → $n_i \simeq 10^{10}\ cm^{-3}$
عدد الالكترونات في الـ Conduction Band عند درجة الحرارة 300°K
GaAs → $n_i \simeq 10^{6}\ cm^{-3}$
Ge → $n_i \simeq 10^{13}\ cm^{-3}$

Scanned by CamScanner

↳ Occupation probability & Carrier Concentration

$$g(E) = \frac{1}{2\pi^2}\left(\frac{2m_c}{\hbar^2}\right)^{3/2}(E-E_c)^{\frac{1}{2}} \qquad E > E_c$$

$$n = \int n(E)\,dE$$

عايزه اعرفها ← n

$$= \int g(E)\,f(E)\,dE$$

$f(E)$ ← probability of occupation

$$\text{Fermi function} = F(E) = \frac{1}{e^{(E-E_f)/kT} + 1}$$

لو عايزه اعرف احتمالية وجود الإلكترون في المستوى E_1 ← E_1

اعوض في القانون عن E بـ E_1 واحسب الـ $f(E)$

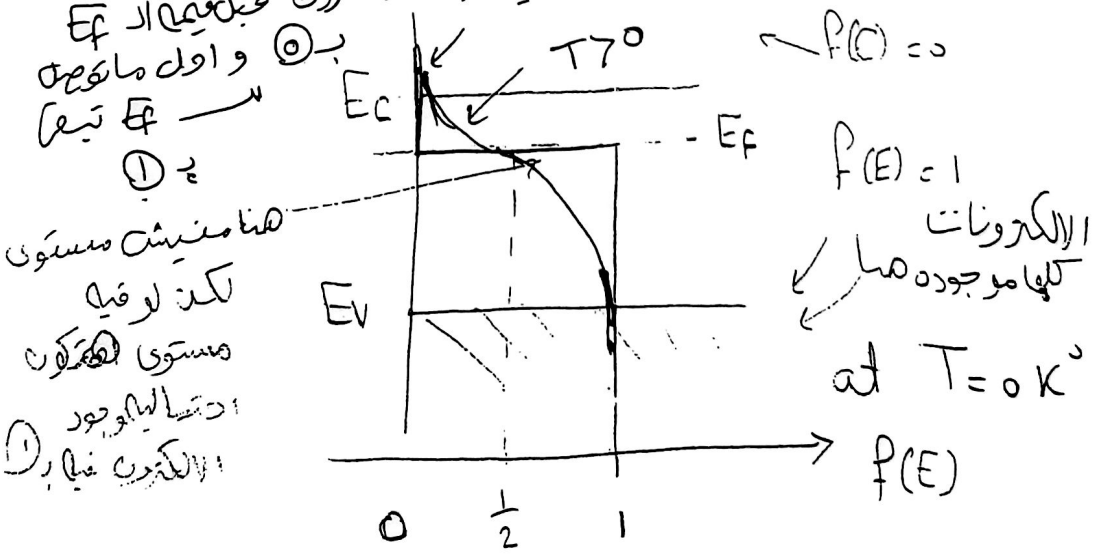
C.B

V.B

E_2

E_f → Constant (Fermi energy)

احتمالية وجود الإلكترون قبل قيمة الـ E_f بـ ⓪ واول ما نوصل لـ E_f تبقى ①

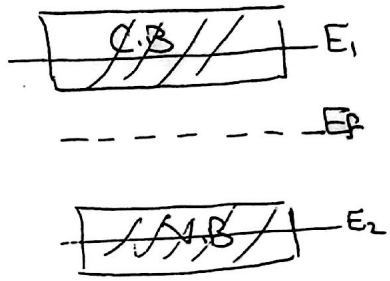


ملناش مستوى لكن لو فيه مستوى الإلكترون احتمالية وجود الإلكترون فيه ①

Scanned by CamScanner

↳ $f(E) = \frac{1}{e^{(E-E_f)/KT} + 1}$

at $T = 0\ K^\circ$

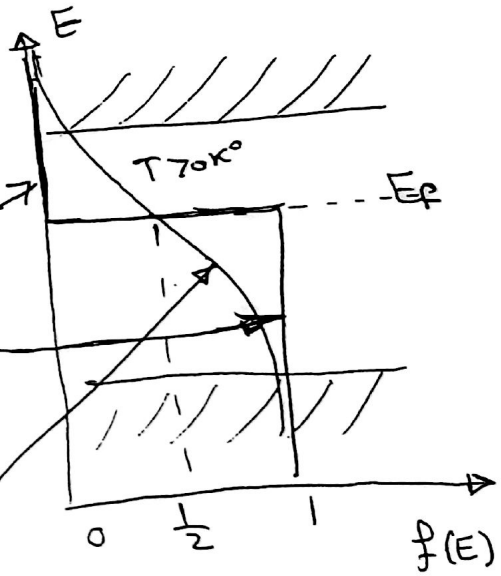


if $E_1 > E_f$

↳ $f(E) = \frac{1}{e^{+\infty} + 1} = 0$

if $E_2 < E_f$

↳ $F(E) = \frac{1}{e^{-\infty} + 1} = 1$



↳ ممكن ان يكون

احتمال وجود الكترونات في ال C.B = 0

احتمال وجود الكترونات بعد الـ Fermi level ← ①

↳ at $T > 0K^\circ$

$T = 300K^\circ$

$E_1 > E_f$ ↳ $f(E) = \frac{1}{e^{+\infty} + 1} \simeq 0$ ~ Small no.

$E = E_f$ $f(E) = \frac{1}{e^0 + 1} = \frac{1}{2} = 0.5$

$E < E_f$ $f(E) = \frac{1}{e^{-\infty} + 1} \simeq 1$

Scanned by CamScanner

Q1 Estimate the following relations for bulk semiconductor materials using Boltzmann's approximation :

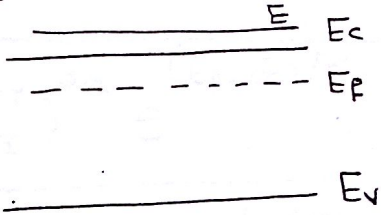
[a] Number of free electrons in C.B.

$$n = \int g_c(E)\, f(E)\, dE$$

In C.B $\quad g(E) = \frac{1}{2\pi^2}\left(\frac{2m_c}{\hbar^2}\right)^{3/2}(E-E_c)^{1/2}$

If i take n-type

$E - E_f \gg KT$



$$\therefore F(E) = \frac{1}{e^{(E-E_f)/KT} + 1}$$

($e^{(E-E_f)/KT}$: large no. — $+1$: discard)

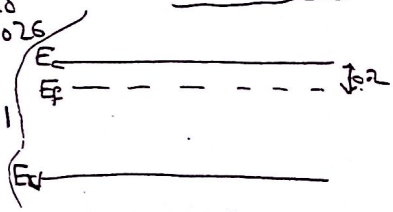
$$\therefore F(E) = e^{-(E-E_f)/KT}$$

للتوضيح بارقام

$KT \simeq 0.026$ eV at $T = 300$

$0.2 / 0.026$

$\therefore e^{8} \gg 1$



$$n = \frac{1}{2\pi^2}\left(\frac{2m_c}{\hbar^2}\right)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2}\, e^{-(E-E_f)/KT}\, dE$$

$$e^{-(E-E_f+E_c-E_c)/KT}$$

$$e^{-(E-E_c)/KT} \cdot e^{\frac{(E_f-E_c)}{KT}}$$

$$n = \frac{1}{2\pi^2}\left(\frac{2m_c}{\hbar^2}\right)^{3/2} e^{\frac{(E_f-E_c)}{KT}} \int_{E_c}^{\infty}(E-E_c)^{1/2}\, e^{-(E-E_c)/KT}\, dE$$

Scanned by CamScanner

$$\therefore n = \frac{(KT)^{3/2}}{2\pi^2}\left(\frac{2m_c}{\hbar^2}\right)^{3/2} e^{\frac{(E_f-E_c)}{KT}} \int_0^{\infty} e^{-x} x^{\frac{1}{2}} dx$$

Let $\frac{E-E_c}{KT} = x$

$\frac{dE}{KT} = dx$

$dE = KT\,dx$

at $E = E_c$ ↳ $x = 0$

$$\int_0^{\infty} e^{-x} x^{\frac{1}{2}} dx \longrightarrow \frac{\sqrt{\pi}}{2}$$

هذا التكامل يحل numerically

$$\therefore \boxed{n = 2\left(\frac{m_c KT}{2\pi\hbar^2}\right)^{3/2} e^{(E_f-E_c)/KT}}$$

↳ $n = N_c\, e^{(E_f-E_c)/KT}$ ↳ no. of electrons in C.B

$N_c = 2\left(\frac{m_c KT}{2\pi\hbar^2}\right)^{3/2}$

b Number of free holes in V.B.

$\therefore E \ll E_f$

$$1 - f(E) = 1 - \frac{1}{e^{(E-E_f)/KT} + 1} = \frac{e^{(E-E_f)/KT}}{1 + e^{(E-E_f)/KT}}$$

فيصبح مقدار بالبسط لـ ① فأقدر أهملها

$$\boxed{1 - F(E) = e^{(E-E_f)/KT}}$$

↳ $P = \int f_V(E)\,(1 - f(E))\,dE$

Scanned by CamScanner

$$P = \frac{1}{2\pi^2}\left(\frac{2m_v}{\hbar^2}\right)^{3/2} \int_{-\infty}^{E_v} (E_v - E)^{\frac{1}{2}}\, e^{(E-E_f)/KT}\, dE$$

$$e^{(E - E_f + E_v - E_v)/KT}$$

$$e^{(E_v - E_f)/KT} \cdot e^{-(E_v - E)/KT}$$

$$P = \frac{1}{2\pi^2}\left(\frac{2m_v}{\hbar^2}\right)^{3/2} e^{(E_v - E_f)/KT} \int_{-\infty}^{E_v} (E_v - E)^{\frac{1}{2}}\, e^{-\frac{(E_v - E)}{KT}}\, dE$$

$$P = \frac{1}{2\pi^2}\left(\frac{2m_v}{\hbar^2}\right)^{3/2} e^{(E_v - E_f)/KT} \int_{-\infty}^{0} x^{\frac{1}{2}} \cdot (KT)^{\frac{1}{2}}\, e^{-x}\, dx\,(KT)$$

let $x = \frac{E_v - E}{KT}$

$dx = \frac{dE}{KT}$

$dE = dx\,(KT)$

$$= \frac{1}{2\pi^2}\left(\frac{2m_v}{\hbar^2}\right)^{3/2} e^{(E_v - E_f)/KT} (KT)^{3/2} \int_{-\infty}^{0} x^{\frac{1}{2}}\, e^{-x}\, dx$$

$$P = 2\left(\frac{m_v KT}{2\pi\hbar^2}\right)^{3/2} e^{(E_v - E_f)/KT} \Rightarrow P = N_v\, e^{(E_v - E_f)/KT}$$

↳ No. of free ~~electrons~~ holes in V.B

Scanned by CamScanner

Intrinsic SemiConductor Material

When electron in an intrinsic SemiConductor get enough energy, it Can go to C.B and leave behind a hole

This process is Called "electron-hole creation"

Free electron → ∴ $n = p = n_i$ ← free hole

n_i : intrinsic Carrier ConCenteration

Scanned by CamScanner

C Intrinsic Carrier Concenteration

for intrinsic material

$$n = P = n_i$$

$$n \cdot P = n_i^2 = N_c N_v \, e^{(E_v - E_f)/KT} \cdot e^{(E_f - E_c)/KT}$$

$$n_i = (N_c N_v)^{1/2} e^{-E_g/(KT)2}$$

E_f الى اليسار ↑

Example: GaAs → $m_c = 0.067\, m_o$ & $E_g = 1.42$ ev
$m_v = 0.45\, m_o$

Calculate intrinsic semiconductor Carrier Concenteration?

Sol

$$N_c = 2\left(\frac{0.067 * 9.1 * 10^{-31} * 1.38 * 10^{-23} * 300}{2\pi\,(1.05 * 10^{-34})^2}\right)^{3/2}$$

$$= 4.74 * 10^{23}\ m^{-3} = 4.74 * 10^{17}\ cm^{-3}$$

$$\hookrightarrow N_v = 2\left(\frac{0.45 * 9.1 * 10^{-31} * 1.38 * 10^{-23} * 300}{2\pi\,(1.05 * 10^{-34})^2}\right)^{3/2}$$

$$= 8.2 * 10^{18}\ cm^{-3}$$

$$\hookrightarrow n_i = (N_c N_v)^{1/2} e^{-E_g/KT}$$

$$= 2.5 * 10^{6}\ cm^{-3}$$

Scanned by CamScanner

C Intrinsic Carrier Concenteration

For intrinsic material

$$n = P = n_i$$

$$n \cdot P = n_i^2 = N_c N_v \, e^{(E_v - E_f)/KT} \cdot e^{(E_f - E_c)/KT}$$

$$n_i = (N_c N_v)^{1/2} e^{-E_g/(KT)2}$$

E_f الطاقة

Example: GaAs → $m_c = 0.067\, m_o$ & $E_g = 1.42\,ev$
$m_v = 0.45\, m_o$

Calculate intrinsic semiconductor carrier concenteration?

Sol

$$N_c = 2\left(\frac{0.067 * 9.1 * 10^{-31} * 1.38 * 10^{-23} * 300}{2\pi\,(1.05 * 10^{-34})^2}\right)^{3/2}$$

$$= 4.74 * 10^{23}\ m^{-3} = 4.74 * 10^{17}\ cm^{-3}$$

$$\hookrightarrow N_v = 2\left(\frac{0.45 * 9.1 * 10^{-31} * 1.38 * 10^{-23} * 300}{2\pi\,(1.05 * 10^{-34})^2}\right)^{3/2}$$

$$= 8.2 * 10^{18}\ cm^{-3}$$

$$\hookrightarrow n_i = (N_c N_v)^{1/2} e^{-E_g/KT}$$

$$= 2.5 * 10^{6}\ cm^{-3}$$

Scanned by CamScanner

[d] Fermi energy for intrinsic materials.

for intrinsic materials

$\because \quad n = p$

$$N_c e^{(E_f - E_c)/KT} = N_v e^{(E_v - E_f)/KT}$$

$$m_c^{3/2} e^{(E_f - E_c)/KT} = m_v^{3/2} e^{(E_v - E_f)/KT}$$

$$e^{2E_f/KT} = \left(\frac{m_v}{m_c}\right)^{3/2} e^{(E_c + E_v)/KT}$$

$$\frac{2E_f}{KT} = \frac{3}{2} \ln\left(\frac{m_v}{m_c}\right) + \frac{E_c + E_v}{KT}$$

$$E_f = \frac{E_c + E_v}{2} + \frac{3}{4} KT \ln\left(\frac{m_v}{m_c}\right)$$

Example Given GaAs $m_c = 0.067\, m_0$

$m_v = 0.45\, m_0$

E_c

E_f

E_v

$$E_f = \frac{E_c + E_v}{2} + \underbrace{\frac{3}{4} KT \ln\left(\frac{m_v}{m_c}\right)}_{0.035}$$

$$E_f \simeq \frac{E_c + E_v}{2}$$

→ Intrinsic Semi Conductor

Scanned by CamScanner

10 Fermi Level energy for N-doped materials

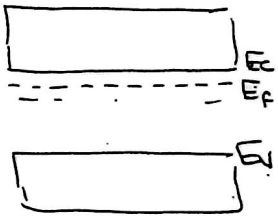
$$n = N_c e^{(E_f - E_c)/KT}$$

$$\frac{n}{N_c} = e^{(E_f - E_c)/KT}$$

$$e^{E_f/KT} = \frac{n}{N_c} e^{+E_c/KT}$$

$$\frac{E_f}{KT} = \ln\left(\frac{n}{N_c}\right) + \frac{E_c}{KT}$$

$$\boxed{E_f = E_c + KT \ln\left(\frac{n}{N_c}\right)}$$



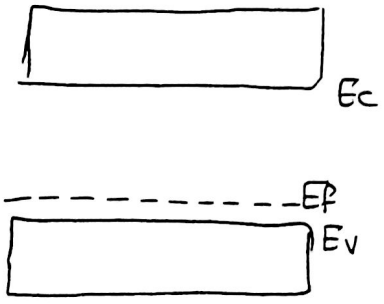
9 Fermi-level energy for P-doped materials

$$p = N_v e^{(E_v - E_f)/KT}$$

$$e^{E_f/KT} = \frac{N_v}{p} e^{E_v/KT}$$

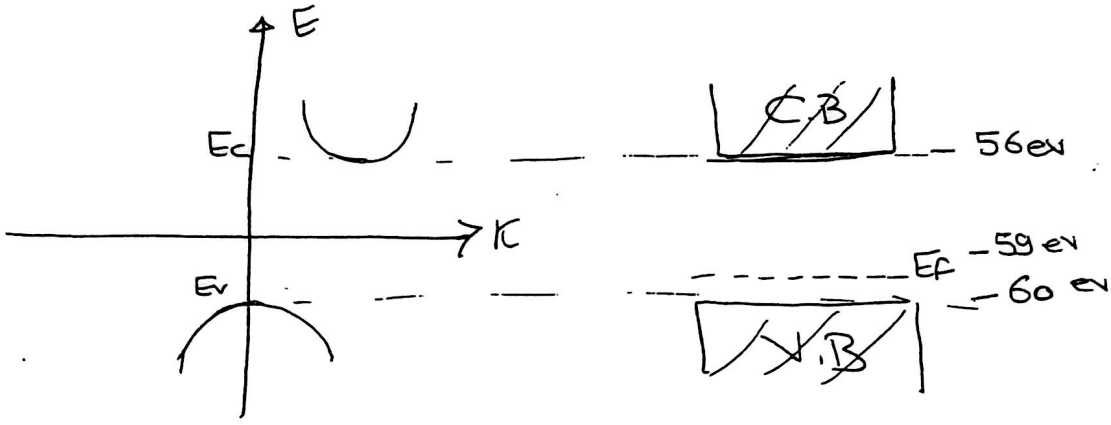
$$E_f = KT \ln\left(\frac{N_v}{p}\right) + E_v$$

$$= E_v - KT \ln\left(\frac{p}{N_v}\right)$$



Scanned by CamScanner

Q(4) Given the following schematics diagrams for semiconductor material where at room temp. $E_c = -56\,eV$, $E_v = -60\,eV$, $E_f = -59\,eV$



Determine

a] The type of material (either direct or indirect) and determine its appropriate application

b] Is the material intrinsic or extrinsic? if it extrinsic, determine if its N-type or P-type. Give reason for your choice?

c] Calculate the probabilites of finding electrons at $E = -55\,eV$, $E = -62\,eV$

d] Calculate the probabilites of finding holes at $E = -62\,eV$

$E = -63\,eV$

~Sol~

a] Indirect bandGap

↳ application → Solar cell / Photo detector

Scanned by CamScanner

b] ① Material is extrinsic

② P-type → E_f is closer to V.B than C.B

c] $f(E)_1\Big|_{E=-55ev} = \frac{1}{e^{(-55+59)/KT}+1} = \frac{1}{e^{4/0.025}+1}$

$\simeq 10^{-70} \simeq 0$

electrons

$F(E)_2\Big|_{E=-62eV} = \frac{1}{e^{-62+59/KT}+1} = \frac{1}{e^{-3/0.025}+1} = 1$

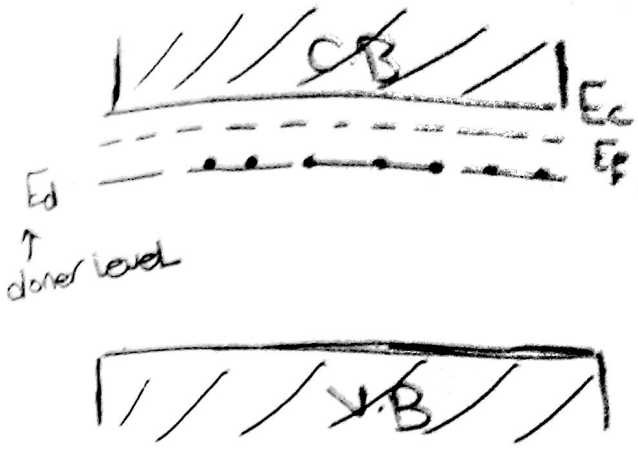
Holes

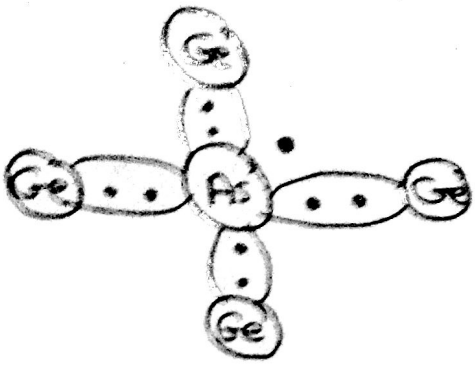
d] ① $f(E)\Big|_{E=-62ev} = 1 - F(E)_2 = 0$

② $1 - f(E)\Big|_{E=-63ev} = 1 - \frac{1}{e^{-4/0.025}+1} = 0$

Scanned by CamScanner

n-type



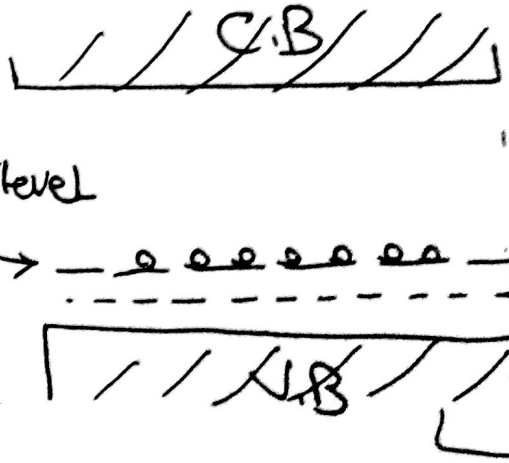


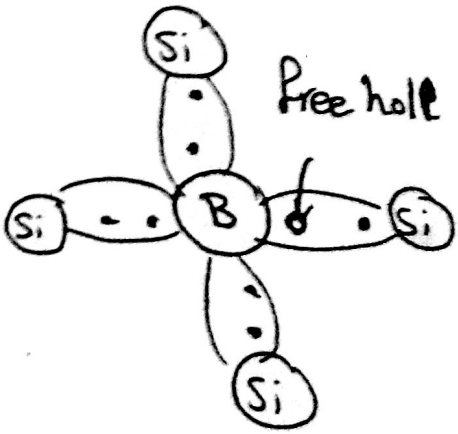
Ge → Group (4)
AS → Group (5)

معناه اني قبل الـ Ef احتمالية وجود
free electrons < 0.5

+ بعدها هيبقى free electrons > 0.5

P-type





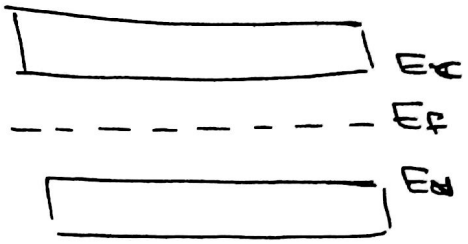
احتمالية وجود
free holes
في الـ V.B ممكن توصل للصفر
لأنها تنتهي بـ $\frac{1}{2}$ و ٩ كبر من الـ $\frac{1}{2}$ عند الـ acceptor level

Ef

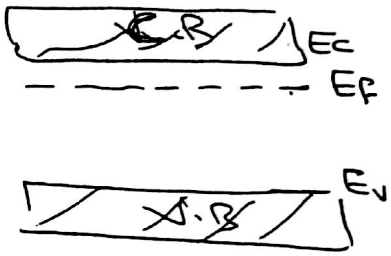
Scanned by CamScanner

Q(2) Draw the energy band diagram and indicate approximate positions for fermi level :

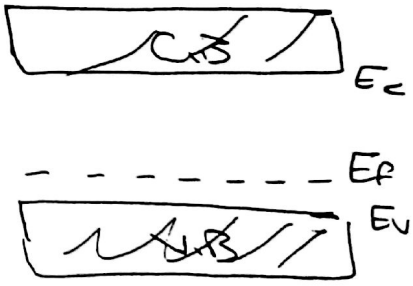
[1] Intrinsic Semi Conductor materials



[2] N-DoPed Semi Conductor materials



[3] P-DoPed Semiconductor materials



Scanned by CamScanner